

# UV testing - 20 years of Data Showing Value for Extended UV Testing of Encapsulant Materials

**Charles Reid, Ph.D.**  
**Chief Technology Officer**  
**STR Solar**

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# “Rule of Thumb” for Xe Arc and PV



*“1 Week in Xe Arc is Equivalent to 1 Year Field Exposure” [1]*

When and How was this derived?

Where is this valid?

What are the assumptions behind this relationship?

[1] Earliest printed citation is 2005

R. Tucker, “Results to Date: Development of a Low-Temperature, Super Fast-Cure Encapsulant”, Paper 5BV.4.8, 20th European Photovoltaic Solar Energy Conference, June 2005, Barcelona, Spain

# Origin: 1 yr Xe arc = 1 yr outdoor



The relationship was first published in 2005 by STR.

- Incorporated using information published in reports from the NREL administered PVMaT phase 3 project.
- This relationship is very specific to a certain set of test conditions and a certain EVA grades.

The relationship may, or may not, be accurate when extrapolated to other conditions or other materials.

... but... This is a starting point for development of accelerated methods

Key Reference: (DOE PVMaT 3 project)

“Advanced EVA-Based Encapsulants, Final Report January 1993-June 1997”

W.W. Holley and S.C. Argo, Specialized Technology Resources, Inc.

September 1998

NREL/SR-520-25296

(US Dept of Energy contract No. DE-AC36-83CH10093)

This reference will be called “**Holley/1998**” with in this document

# Background – early 1990's

## Goals of PVMaT 3:

- Why did EVA-based encapsulants turn yellow or brown?
- What was the mechanism?
- What test methods can be used to simulate this?

## Key Conclusions (Holley/1998)

- Color formation was due to creation of chromophores created by mixture of polymer additives exposed to light, heat and humidity
- Glass type (cerium, non-cerium) was a confounding factor
  - Less yellowing occurs with UV-blocking glass, or cerium-glass
- Accelerated UV and Temperature replicated field observations for EVA browning of first-generation formulations

# Materials:

Holley/1998 describes several different commercial and pre-commercial EVA based encapsulant products. One encapsulant material was used for the purpose of deriving the correlation between xenon arc and natural weathering:

**EVA Encapsulant = STR PHOTOCAP<sup>®</sup> A9918P (1<sup>st</sup> generation EVA for PV)**

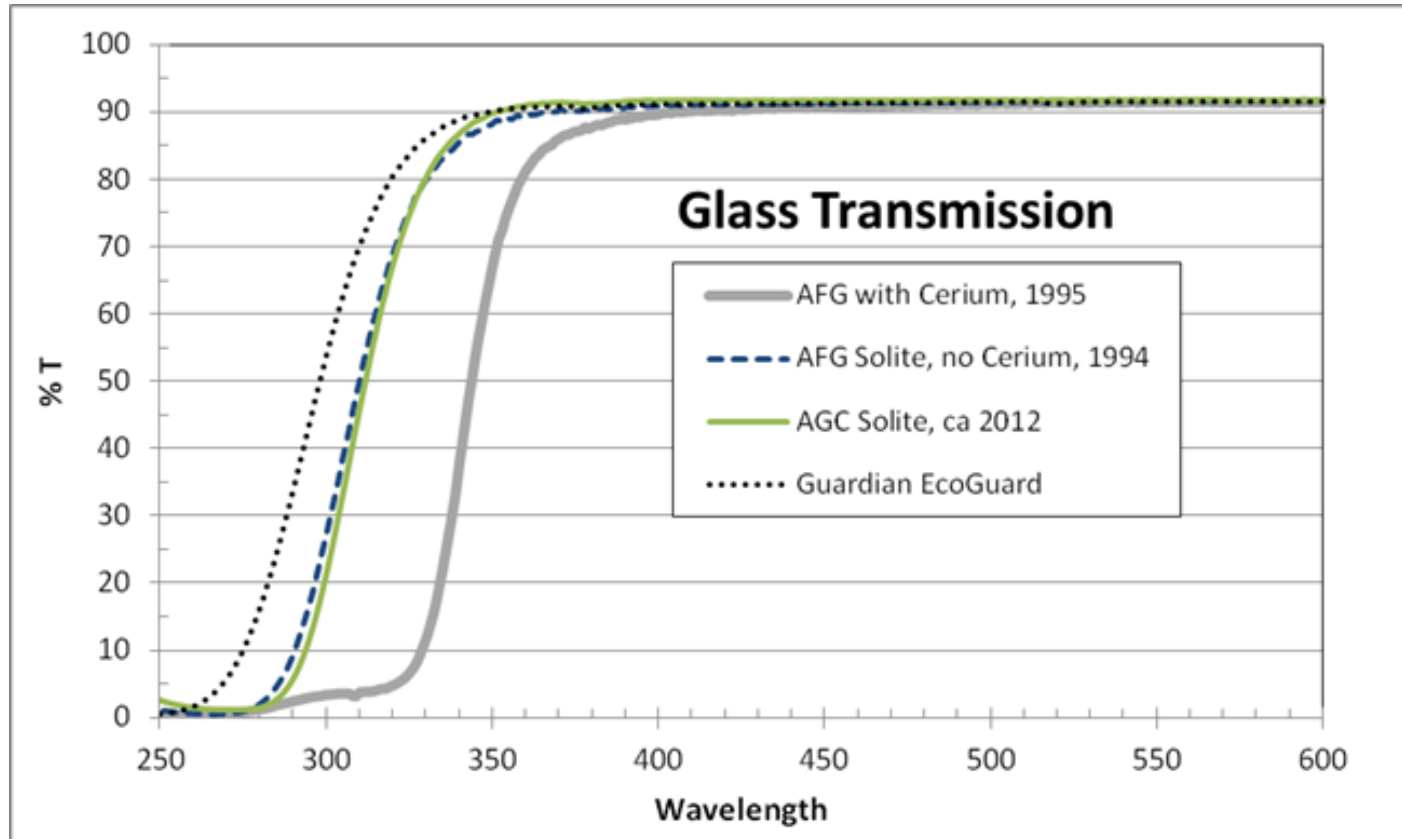
Two different **glass grades** were used for this correlation work. Both grades are **non-cerium**, low iron glass intended for use in solar photovoltaic applications.

**AFG Solite<sup>®</sup>**

**PPG Starphire<sup>®</sup>**

*AFG Solite is still commercially available from AGC and is in commercial use.  
PPG Starphire is also commercially in use for solar industry.*

# Glass Transmission Spectra



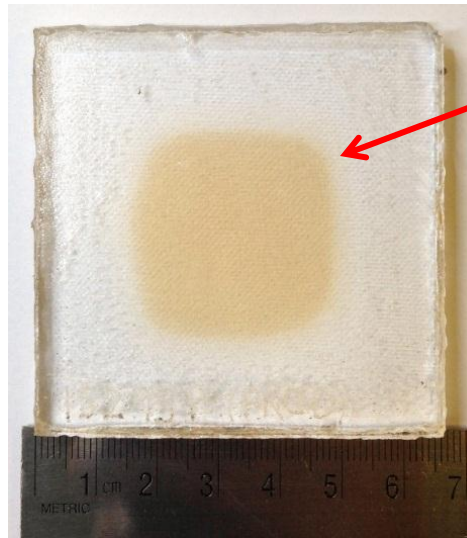
Cerium containing glass blocks significant amount of UV light

# Test Coupons

PV Module, ~15 years  
Arizona. Encapsulant is  
PHOTOCAP 15295



Picture of Xe Arc Aged Coupon:  
Glass-EVA-Glass, 70 x 70 mm



Yellowness Index ~ 35  
Measurement made in  
center

Note – edges are not  
sealed.

Yellowing in center of  
cell (or glass coupon) is  
the result of competing  
mechanisms, additive  
yellowing, and  
oxidative bleaching.

Klemchuk, P., Ezrin, M., Lavigne, G., Holley, W., Galica, J. and Argo, S.,  
“Investigation of the Degradation and Stabilization of EVA-Based Encapsulant in  
Field-Aged Solar Energy Modules,” Polymer Degradation and Stability, Vol 55,  
pp 347-365 (1997).

# Xenon Arc Exposure

Test conditions were changed about 1999 after the PVMat-3 project was completed. These conditions yielded better instrument reliability.

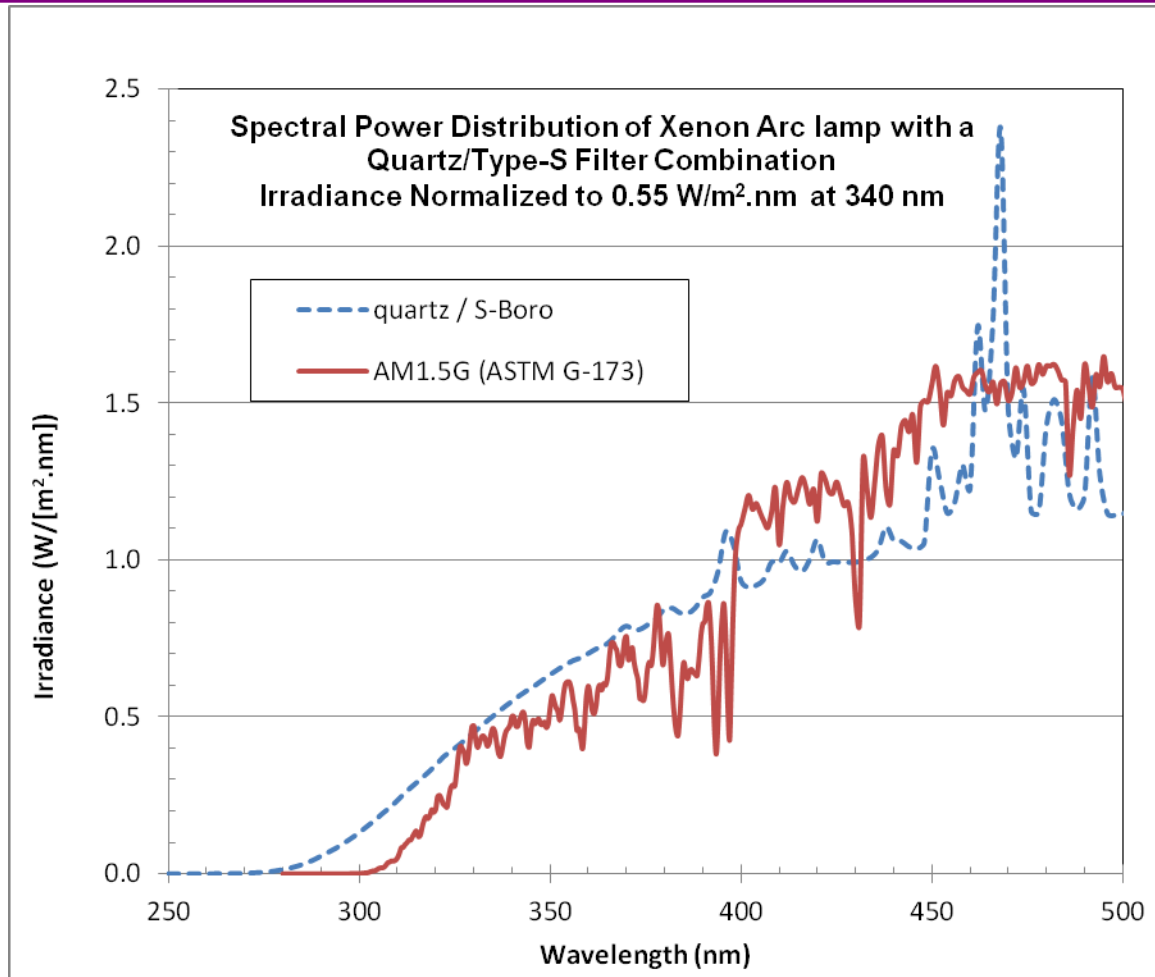
	<b>STR Test Conditions for 1993-1996</b>	<b>STR Test Conditions (1999 to Current)</b>
<b>Bulb</b>	Xe arc, water cooled	Xe arc, water cooled
<b>Bulb filters **</b>	Quartz (inner) Type S borosilicate (outer)	Quartz (inner) Type S borosilicate (outer)
<b>Irradiance Control</b>	340 nm, fixed at 0.55 W/m <sup>2</sup> /nm	340 nm, fixed at 0.55 W/m <sup>2</sup> /nm
<b>Light Cycle</b>	Continuous. No dark cycle	Continuous. No dark cycle
<b>Temperature</b>	100 °C, black panel (uninsulated)	90 °C, black panel (uninsulated)
<b>Air Temperature</b>	Unknown / not recorded	70 °C
<b>Relative Humidity</b>	> 95%, constant	50%, constant
<b>Water Spray</b>	Not used	Not used

\*\* This filter combination gives the spectral power distribution described in SAE J2527, Table C1 (Extended UV Filters).

These test conditions can be achieved with several different testing machines



# Xenon Arc Spectral Power Distribution



At 26 weeks of exposure,  
STR's Xe arc irradiance  
exposure is:

**~3X** IEC 61345  
for 280-320 nm exposure

**~16X** IEC 61345  
for 320-400 nm exposure

This filter combination and  
SPD is the same as  
SAE J2527-C1  
(former J1960) Used for  
automotive exterior  
components

With this filter combination, the UV spectral distribution  
is a additional accelerating factor (combined with T and %RH)

# Outdoor Testing: Equatorial Mount Mirror Acceleration

Equatorial mount mirror acceleration (EMMA<sup>®</sup>) was performed by DEST Labs in Phoenix, Arizona, in mid 1990's. This laboratory is now owned by Atlas Material Testing Technology.

EMMA is a ground mounted mirror and fresnel lens based accelerated aging protocol. **EMMA ~1995 achieved about 4X UV acceleration and 7-8X visible light acceleration.** The method also accelerates temperature and holds the test specimens at a higher temperature than ambient conditions.

Additional information can be found at:

<http://atlas-mts.com/services/natural-weathering-testing/accelerated-weathering/emmaqua>



Image from Atlas Material Testing Technology

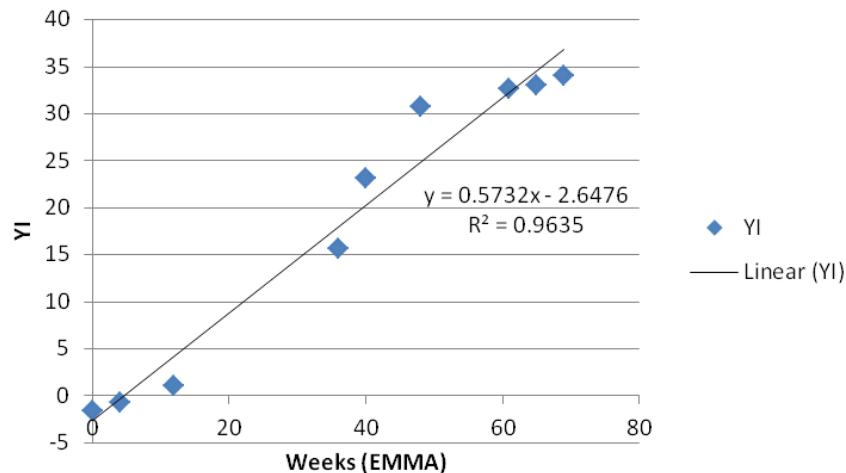
The EMMA used in mid 1990's did not have temperature control and humidity/water spray was not used.

The aging reported in Holley/1998 is for dry aged, accelerated irradiance and elevated temperatures.

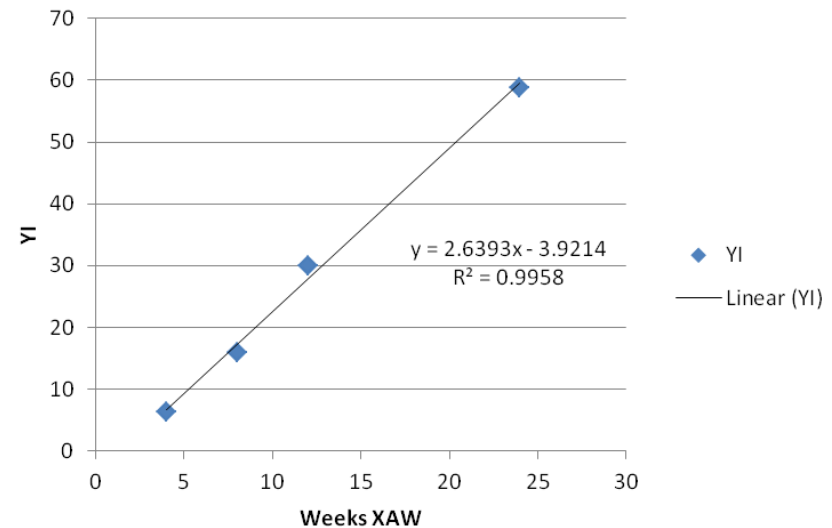
# Results: XAW & EMMA – 1990's

Data published in Table 4 & 7 of **Holley/1998**

**Table 4 (A9918/Starphire - EMMA)**



**Table 7 - A9918 - XAW**



Sample:

EVA = STR A9918P (first generation EVA encapsulant, commercialized 1979)

Glass = PPG Starphire (non Cerium)

Yellowness index increases monotonically with increased UV exposure with both methods.

# 1990's XAW vs EMMA Correlation



EMMA: 5X acceleration of UV exposure  
1 week EMMA = 5 weeks Arizona

$$\frac{10.4 \text{ week EMMA}}{1 \text{ year Arizona}} \bullet \frac{0.57 \text{ YI Units}}{1 \text{ week EMMA}} \bullet \frac{1 \text{ week XAW}}{2.6 \text{ YI Units}} \approx \frac{2.3 \text{ week XAW}}{1 \text{ year Arizona}}$$

## *Further Simplification:*

Solar irradiance in Arizona is about 2X that of Northern industrialized climates, such as Germany and North East USA. Thus, the relationship has been extrapolated to be :

1 week XAW ~ 1 year Outdoor exposure

## CAVEATS:

Relationship is based upon yellowing of STR PHOTOCAP A9918 with Glass-EVA-Glass coupons. Interaction effects between encapsulant and PV cells are neglected.

The relationship uses both EMMA and Xenon arc, both of which have accelerated irradiance and elevated temperatures.

# A9918 Modules from 1997

Modules added by STR to the PVMaT-3 module study as controls.

12 modules that differ only by the type of glass used:

- Cerium containing versus Non-Cerium glass were used
- Encapsulant was PHOTOCAP A9918 in all 12 modules

## Power tests from 1997:

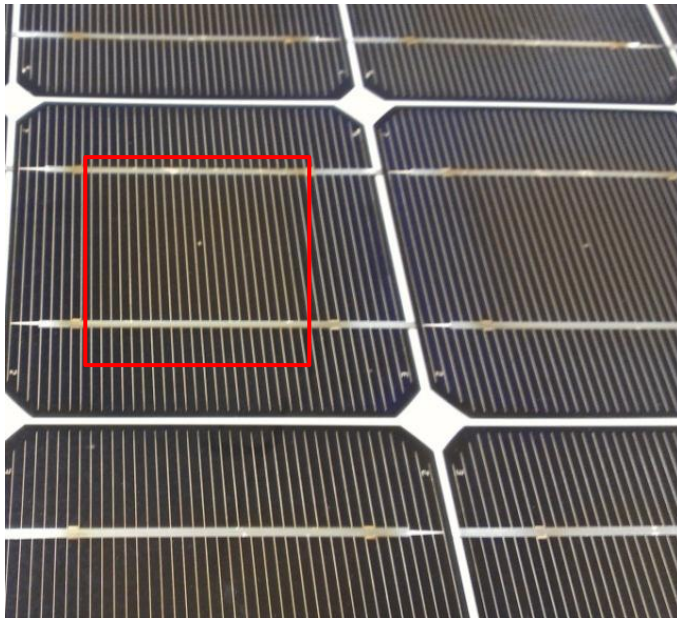
Encap.	Glass		Isc (A)	Voc (V)	FF%	Pmax (W)
<b>A9918</b>	<b>Cerium</b>	Avg of 6	3.27	21.7	73%	50.0
		Stdev	0.03	0.2	2%	1.2
<b>A9918</b>	<b>Starphie (non cerium)</b>	Avg of 6	3.33	21.6	73%	50.9
		Stdev	0.02	0.1	2%	1.5
	Non-Cerium vs. Cerium	Difference	1.8%	-0.2%	-0.1%	1.6%

Non-cerium glass yielded ~1.6% power increase due to more photons striking the surface of the PV cells (higher Isc, but constant Voc).

# A9918 Modules from 1997

## Pictures from 2012

Modules Exposed for 15 Years, 2-axis Tracker, Phoenix, Arizona  
Encapsulant = PHOTOCAP A9918, same manufacturer



Glass with cerium

Yellowing only in center of cell



Glass without cerium  
(PPG Starphire)

Yellowing over entire cell.

# A9918 Modules from 1997, Tested 2012

## Power Tests on Tracker, Natural Sunlight (ASU-PTL)

Encap.	Glass		Isc (A)	Voc (V)	FF%	Pmax (W)
A9918	Cerium	Avg of 6	3.18	21.4	54%	36.6
		Stdev	0.02	0.1	7%	4.4
A9918	Starphie (non cerium)	Avg of 6	2.82	21.5	58%	35.7
		Stdev	0.06	0.2	5%	3.5
	Non-Cerium vs. Cerium	Difference	-11.4%	0.6%	8.2%	-2.3%

Power Tests 2012,  
After 15 years  
exposure 2-axis tracker

Non-Cerium relative to  
Cerium (A9918):  
Lower Isc and  
Lower Pmax

## Power Tests with Solar Simulator, 23°C – after cleaning. (STR R&D, East Windsor, CT)

Encap.	Glass		Isc (A)	Voc (V)	FF%	Pmax (W)
A9918	Cerium	Avg of 6	3.27	21.4	54%	37.8
		Stdev	0.03	0.1	6%	3.8
A9918	Starphie (non cerium)	Avg of 6	2.95	21.3	56%	35.1
		Stdev	0.06	0.0	5%	3.5
	Non-Cerium vs. Cerium	Difference	-9.7%	-0.2%	3.1%	-6.9%

Isc: short circuit  
current is directly  
proportional to photon  
energy delivered to the  
PV cell.



# A9918 Modules from 1997

Power Tests: 2012 relative to 1997:

Exposure = 15 years, two-axis tracker, or “effective” 24 years fixed axis

Encap.	Glass		Isc (A)	Voc (V)	FF%	Pmax (W)
<b>A9918</b>	<b>Cerium</b>	Change	100%	98%	74%	75%
<b>A9918</b>	<b>Starphie (non cerium)</b>	Change	89%	98%	77%	69%

Conclusions:

Non-cerium glass yielded in **11% loss of Isc, and 6% loss of power**. These are the effects due only to EVA browning, due to exposure to UV light.

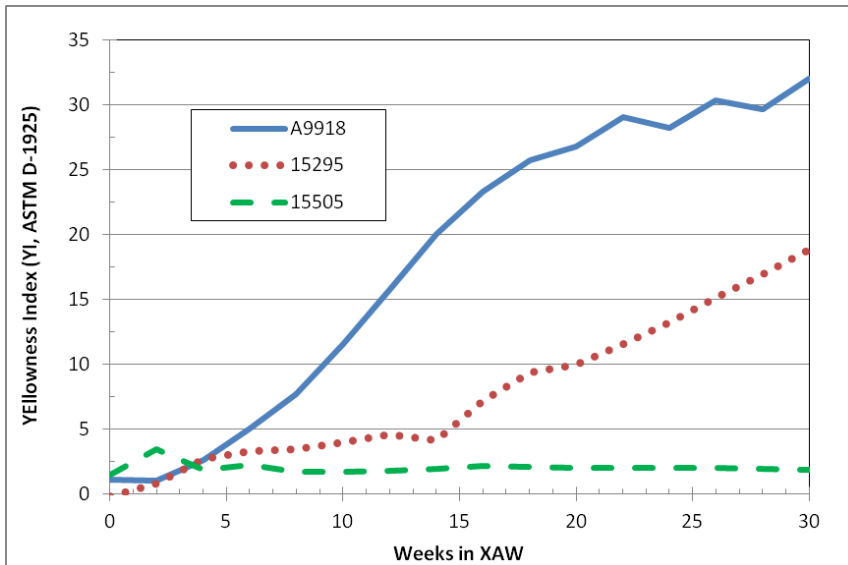
Voc is unchanged.

Fill factor shows ~25% loss, due to factors other than encapsulant browning.

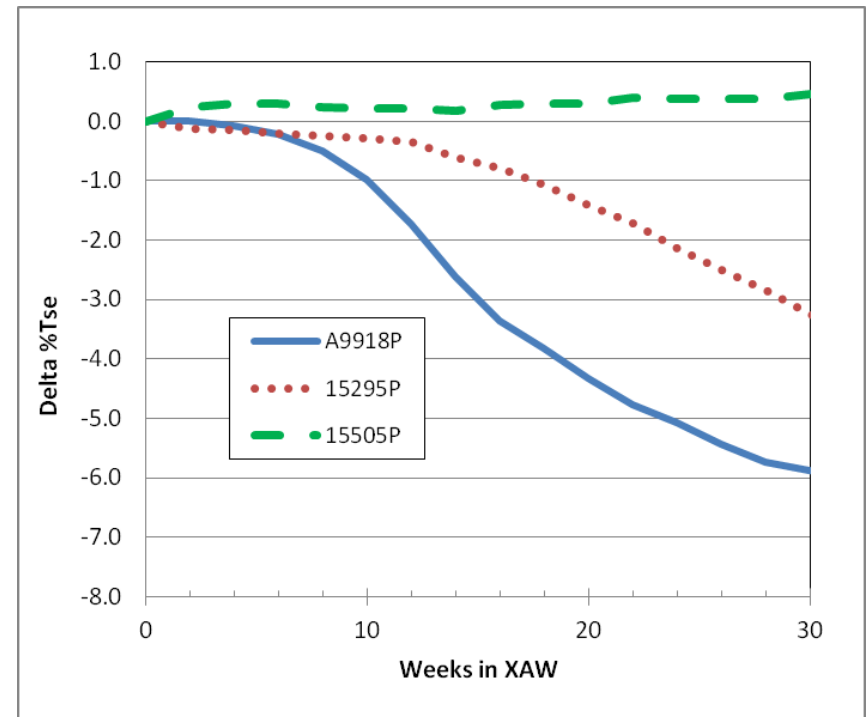


# Xenon Arc Aging: 2010-2012 Tests

Xenon arc aging using current conditions.  
Non cerium glass



Yellowness index



%Tse – solar energy weighted %Transmission

$$T_{SE} = \sum_{\lambda=350nm}^{\lambda=1200nm} T_{\lambda} \times E_{\lambda}$$

Decrease in %Tse is approximately equal to expected power loss

# “New” Xe-Arc and Outdoor Aging Correlation



Outdoor aging for 1<sup>st</sup> generation EVA A9918:

- Isc decreases by 11% in 24 yrs fixed-mount exposure, Arizona
- Use 10% as conservative metric

Xenon arc aging (STR conditions)

- %Tse decreases by 6% in 30 weeks of aging

Assume %Tse causes equivalent decrease of Isc:

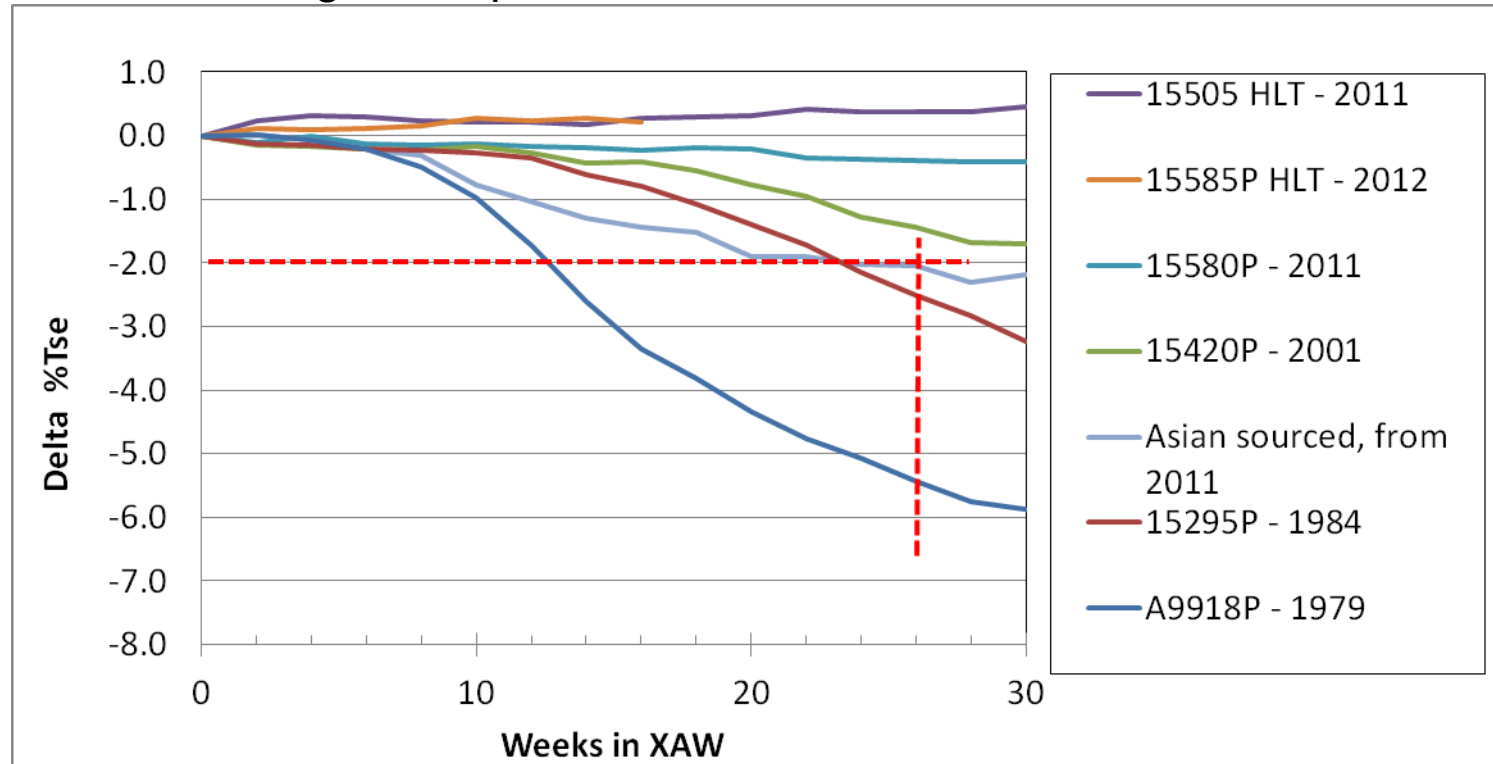
$$\frac{30 \text{ week XAW}}{6\% \text{ loss \%Tse}} \bullet \frac{10\% \text{ loss Isc}}{24 \text{ years Arizona}} \cong \frac{2.1 \text{ week XAW}}{1 \text{ year Arizona}}$$

Surprisingly, the acceleration factor from Xe arc to outdoor Arizona fixed axis exposure is the same as derived from 1994-1997 tests.

# Xe Arc – Modern Encapsulants

2% Loss of %Tse at 26 weeks of Xe Arc Exposure – Reasonable Expectation for High Performing Encapsulating Materials.

STR's Current Generation of Products Show Significantly Less Change in Optical Transmission during UV Exposure.



# Is EVA-Browning Fully Understood?



For EVA alone – **Yes:**

- Component test of encapsulant and glass is well studied and understood.
- Tests described here are used for development of new encapsulant formulations

For EVA in Contact with Other Components – **Yes & No**

- Encapsulant and backsheet interactions
- Interaction of encapsulant with metals on surface of cell
  - Conductive fingers
  - Anti Reflection coatings
  - Soldering components
- Electric field aging mechanisms (eg, electrophoresis)

# Conclusions

## Xenon Arc Tests Strongly Correlated with Field Aging:

- Yellowing of first-generation EVA-based PV encapsulants
- PHOTOCAP A9918
- Outdoor tests:
  - Mirror accelerated aging, 1995-1996
  - 2-axis tracker aging, 1997-2012

## Xenon Arc Methods is Recommended as Acceptance Criterion for New PV Encapsulants:

- STR test conditions: 0.55 W/m<sup>2</sup>/nm, 90°C Black Panel, SAE J2527 Table C1 spectra (Extended UV filters)
- Test for >26 weeks (4,368 hrs) continuous light
- Suggest < 2% change in %Tse as criterion at 26 weeks

## International PV-QA, Group 5, Studying Effects of UV on PV Modules

- Multi-Laboratory study of A9918, 15295, and other EVA samples
- Xenon arc, fluorescent UV lamps (UVA, UVB), and Hg lamps, to be studied
- Planned for 2013-2014

**THANK YOU**

Americas	Europe	Asia
Specialized Technology Resources, Inc. 18 Craftsman Road East Windsor, CT 06088 USA Phone: +1 860-763-7014 ext: 2560 Email: <a href="mailto:sales@strsolar.com">sales@strsolar.com</a>	Specialized Technology Resources, España Parque Tecnológico de Asturias, parcela 36 33428 Llanera, Asturias SPAIN Phone: +34 985 73 23 33 Email: <a href="mailto:sales@strsolar.com">sales@strsolar.com</a>	Specialized Technology Resources, Malaysia Plot D20, Jalan Tanjung A/3 Port of Tanjung Pelepas 81560 – Gelang Patah, Johor MALAYSIA Phone: +607 507 3185 ext:113 Email: <a href="mailto:sales@strsolar.com">sales@strsolar.com</a>

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